CHAPTER 8

CONCRETE MOMENT RESISTING FRAMES

8-1. Introduction. This chapter prescribes the criteria for the design of reinforced concrete moment resisting frames of buildings in seismic areas; indicates principles, factors, and concepts involved in seismic design of moment resisting frames; gives design data; and illustrates typical details of construction.

8-2. General.

a. Function. Moment frames, like shear walls, are vertical elements in a lateral force resisting system that transmit lateral forces to the ground; however, they differ from shear walls in that their deflections result primarily from flexural deformations of their elements.

b. Frame behavior. The bending stiffness of the moment resisting frame provides the lateral stability of the structure (fig 8-1). It is important to remember that deformations resulting from the dynamic response to a major earthquake are much greater than those determined from the application of the prescribed design forces. This means that a frame that meets the minimum strength requirements of this manual will survive a major earthquake only if it can yield and sustain cyclic inelastic deformations without essential loss of lateral resistance and vertical load capacity. Since normal building materials have very limited energy-absorbing capacity in the elastic range of action, it follows that what is needed is a large energy capacity in the inelastic range. The term *ductility* is used to denote this property. Providing a ductile seismic frame will allow the structure to sustain tolerable and, in many cases, reparable damage, instead of suffering catastrophic failure. The energy dissipation, ductility, and structural response (deformation) of moment resisting frames depend upon the types of members, connections (joints), and materials of construction used. The behavior of joints is a critical factor in the ability of building frames to resist high-intensity cyclic loading.

8-3. Classification of concrete seismic moment resisting frames. In this manual, concrete moment resisting frames are classified as Types A, B, C, and D according to their particular design provisions and details. The classification ranges from the most ductile and energy absorptive, Type A, to the least ductile, Type D. These types are related to the special moment resisting frame (SMRF), the intermediate moment resisting frame (IMRF), and the ordinary moment resisting frame (OMRF), as defined in SEAOC 1B. Type A is equal to the SMRF; Type B is the IMRF with some specific provisions for bar development, and splices of reinforcing; Type C is the OMRF with some specific provisions for continuity of reinforcing, bar development, and splices; Type D is the OMRF designed according to ACI Chapters 1 through 12. The requirements governing the use of Types A, B, C, and D depend upon the seismic zone and its corresponding level of seismic demand; the R_w-value employed and its inferred amount of inelastic energy dissipation capability; and whether the frame is the primary designated lateral force resisting system or is the remaining nondesignated (but gravity load bearing) part of the complete space frame. Table 8-1 shows the reinforced concrete frame systems organized according to the classification of structural systems that is shown in SEAOC Table 1-G. Table 8-1 is a refinement of SEAOC Table 1-G, showing where the particular frame types are either required or permitted.

8-4. Type A frames. This type is the SEAOC SMRF. It has the highest degree of energy dissipation capacity and is required in the designated moment resisting frame systems in Zones 3 and 4. The basic concept of Type A frames is to provide inelastic energy dissipation by flexural yielding in the girder elements. Columns must, therefore, be stronger than the flexural capacity of the girders, and all elements must have shear resistance and reinforcing bar anchorage capacity capable of developing the full flexural yield level in the girders.

a. General design requirements. This paragraph summarizes the provisions given in Chapter 21 of ACI 3 18-89 and the additional requirements of the manual. In order to provide the girder yield mechanism, the design provisions require:

(1) Compact proportions for the girder and column sections, along with closely spaced seismic ties or hoops for confinement of concrete in the regions of potential flexural yielding.

(2) Column interaction flexural capacity greater than 6/5 times the value required to develop girder yield.

(3) Girder, column, and joint shear capacity greater than shears induced by gravity loads and the strain-hardened flexural capacity of the girders.

(4) Reinforcing bar splices and straight and hooked bar anchorages capable of developing the strain-hardened yield of the girder steel.

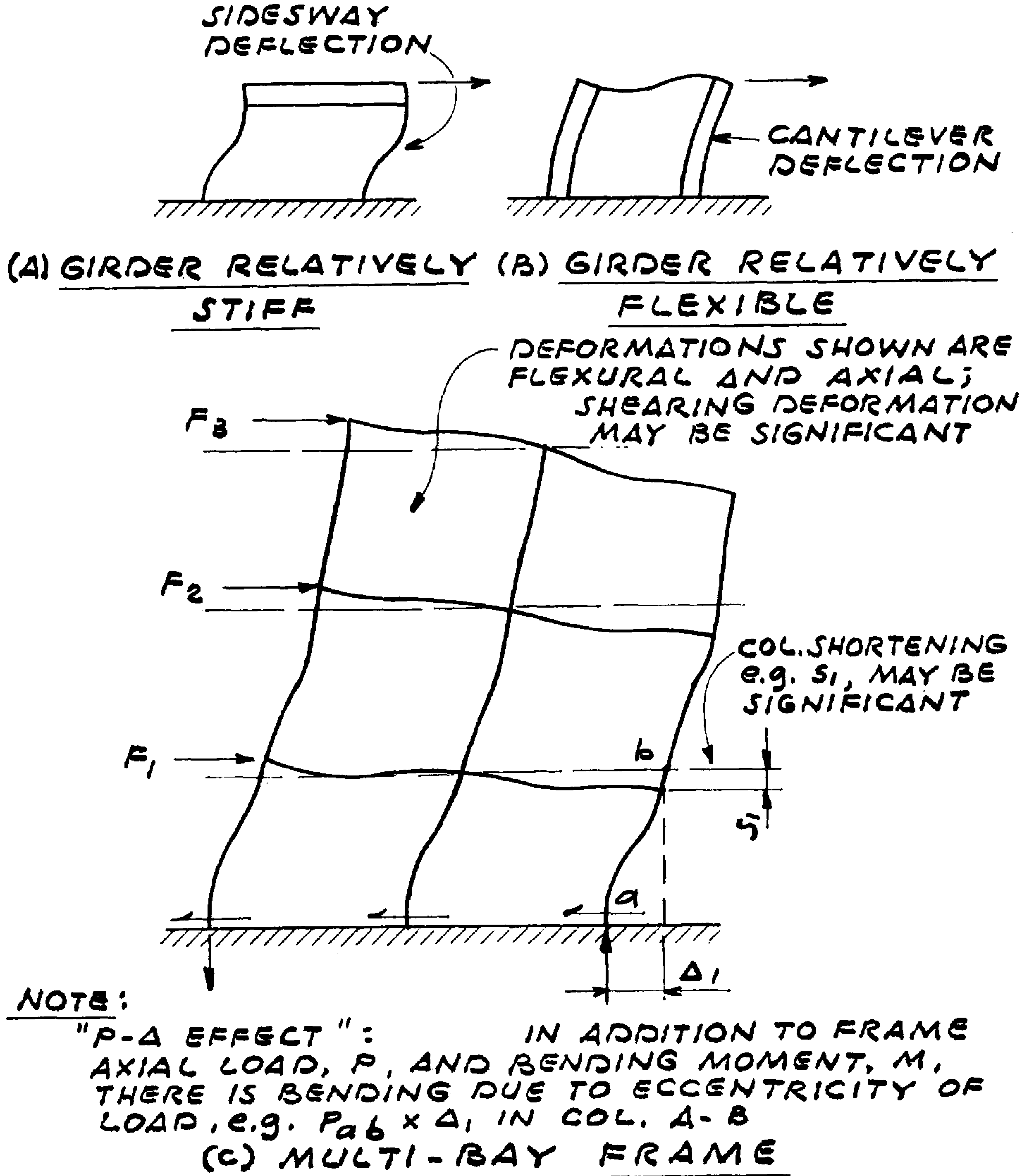


Figure 8-1. Frame deformations.

Structural System	R_w	H	Seismic Zone 3&4	Seismic Zone 1&2
SEAOC B. Building frame system				
3a. Concrete shear walls				
Concrete frames that are not part of the lateral force resisting system:				
Frame Type C	8	240 ft	Yes	No
Frame Type D	8	--	No	Yes
SEAOC C. Moment resisting frame system*				
lb. Type A	12	--	Yes	Yes
2. Type B	7	--	No	Yes
3b. Type C	5	--	No	Not in 2
SEAOC D. Dual System*				
1a. Concrete shear walls with Type A moment frames	12	--	Yes	Yes
1b. Concrete shear walls with Type B moment frames	9	160 ft	Yes	Yes
3b. Concrete concentric braced frames with Type A frames	9	--	No	Yes
3c. Concrete concentric braced frames with Type B frames	6	--	No	Yes

*Concrete frames not part of the designated lateral force resisting system will be Type C in Zones 2, 3, and 4, and may be Type D in Zone 1.

Table 8-1. Concrete moment resisting frame systems.

b. The two phases of design. With the design concept that inelastic behavior and energy dissipation are to be restricted to flexural yielding in the confined concrete regions of the beam or girder elements, the design process consists of two phases. The first phase establishes the beam sizes and capacities needed to resist the specified factored gravity and seismic load combinations. Then, with the known girder strengths and some preliminary column sizes, the second phase proportions the shear resistance of the girders, columns, and joints and establishes the column flexural strengths such that all of these elements are able to resist the effects of a strain-hardened flexural yielding in the beams along with unfactored gravity loads. The related specific requirements and details are shown in figures 8-2 to 8-9, and the design procedure is given by example in appendix D.

8-5. Type B frames. This type is the SEAOC IMRF with some modifications. It has a moderate degree of energy dissipation capacity. Its use is limited to Zones 1 and 2. It may be used as the designated moment resisting frame in a building frame system $R_w = 7$. It may be used as the moment resisting frame of a dual system, as follows: with concrete concentric braced frames, with $R_w = 6$; with masonry shear walls, with $R_w = 7$; and with concrete shear walls, with $R_w = 9$. These R_w-values represent lesser ductility compared with the Type A frame. The design provisions are essentially those of ACI 21.9, with additional requirements given in the following paragraphs. The additional requirements are intended to provide for structural resistance to collapse due to the rare but credible earthquake effects in Zones 1 and 2.

a. Slab and column frames. Flat-plate or two-way slab systems are permitted for the beam elements of Type B frames. These slab systems have a potential for a brittle mode of punching shear failure at the column supports due to gravity load combined with the eccentric shear caused by moment transferred from the slab to the column. In order to prevent punching-shear failure under the maximum expected earthquake deformation, the slab will have the capacity to resist nonfactored gravity load effects together with the transfer moment effects due to $3R_w/8$ times the specified seismic forces. The value of the transfer moment M_u used for the fraction $\gamma_v M_u$ to be transferred by eccentricity of shear will therefore be due to the load combination of D + L +

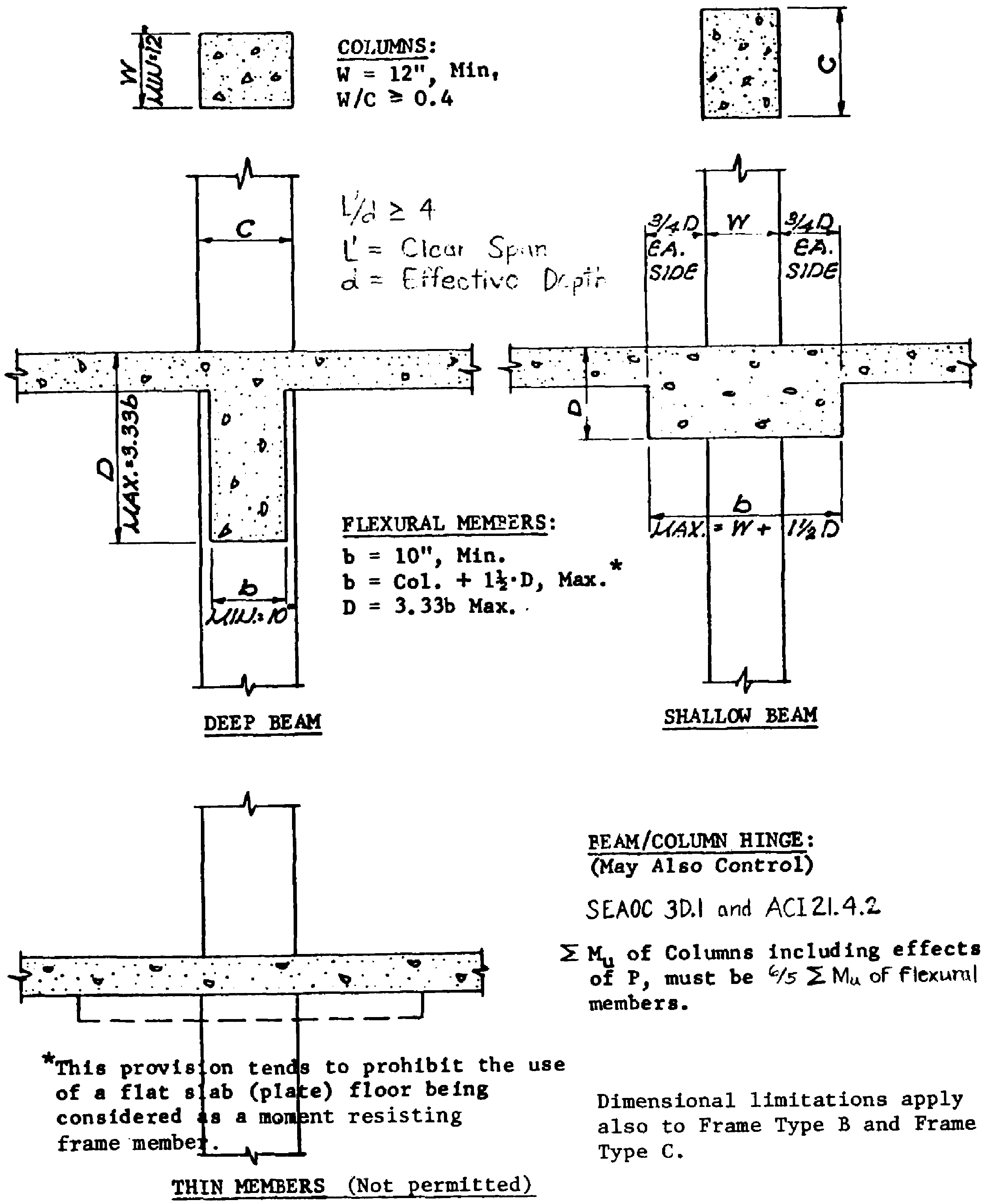
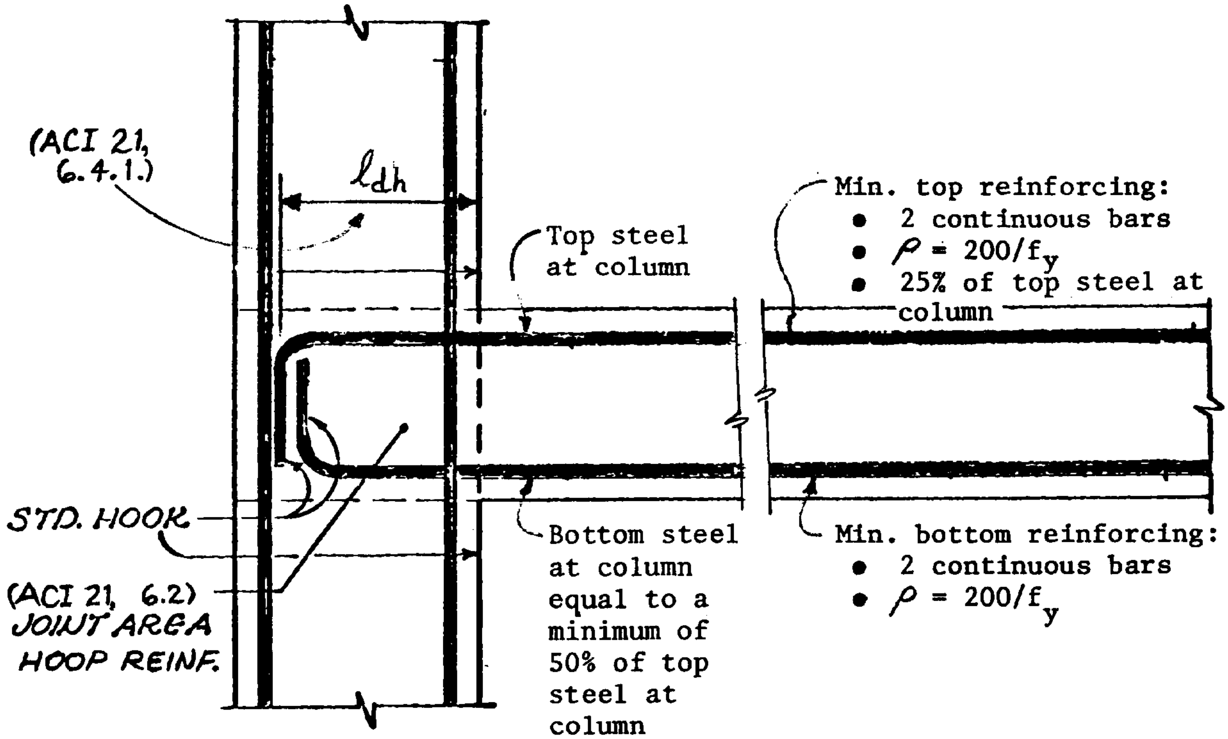


Figure 8-2. Type A frame—limitations on dimensions.



ELEVATION OF GIRDER AND COLUMN

FLEXURAL MEMBER:

f'_c = 3,000 p.s.i. min. at 28 days

f_y = 40 ksi or 60 ksi

Reinforcement ratio, $\rho = A_s/bd$ or $\rho' = A'_s/bd$: ρ = 0.025 max.

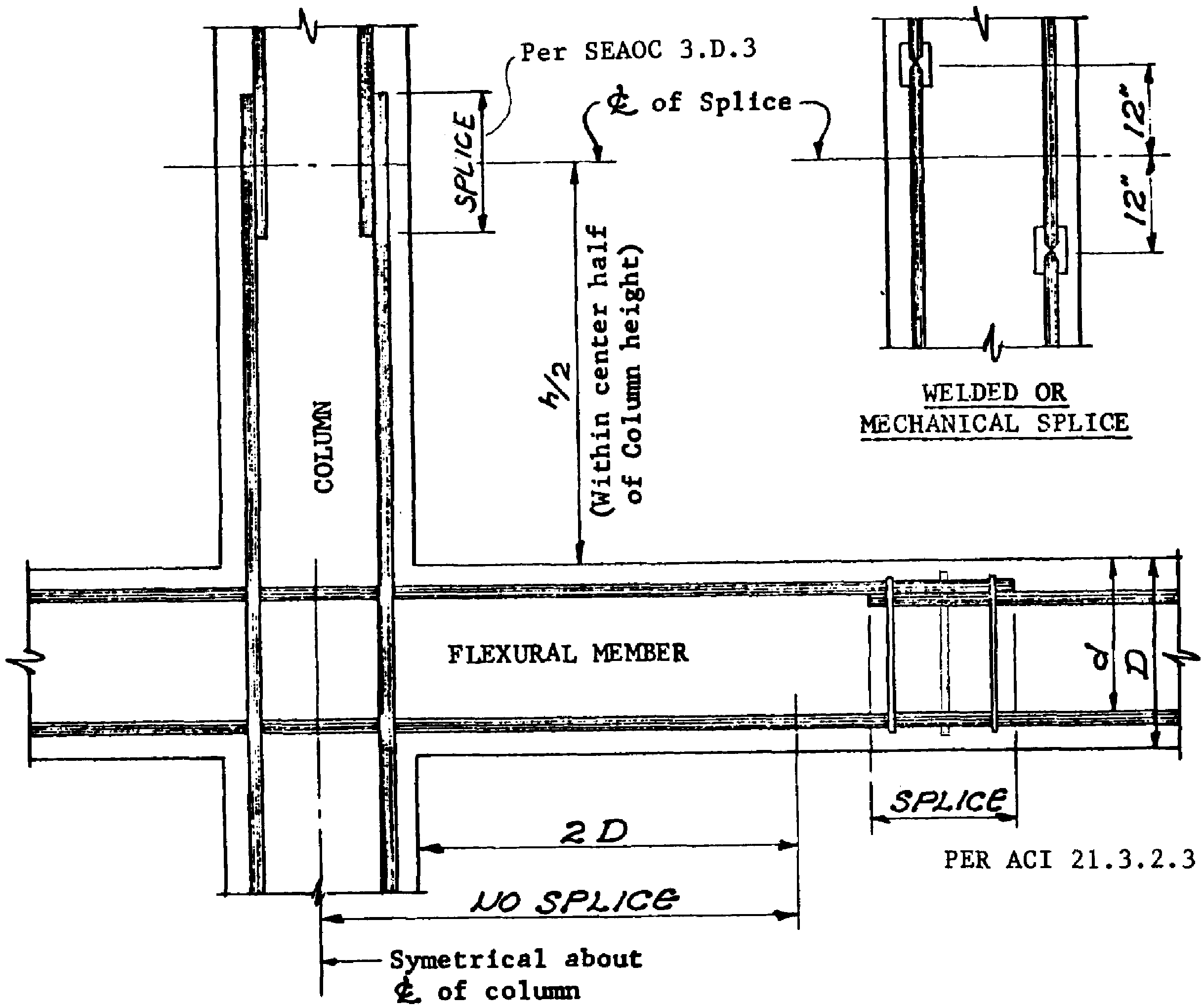
COLUMN:

f'_c = 3,000 p.s.i. at 28 days Min.

f_y = 40 ksi or 60 ksi

Reinforcement ratio, ρ (for tied columns)
$\geq$ 0.01 and $\leq$ 0.06.

Figure 8-3. Type A frame—longitudinal reinforcement.

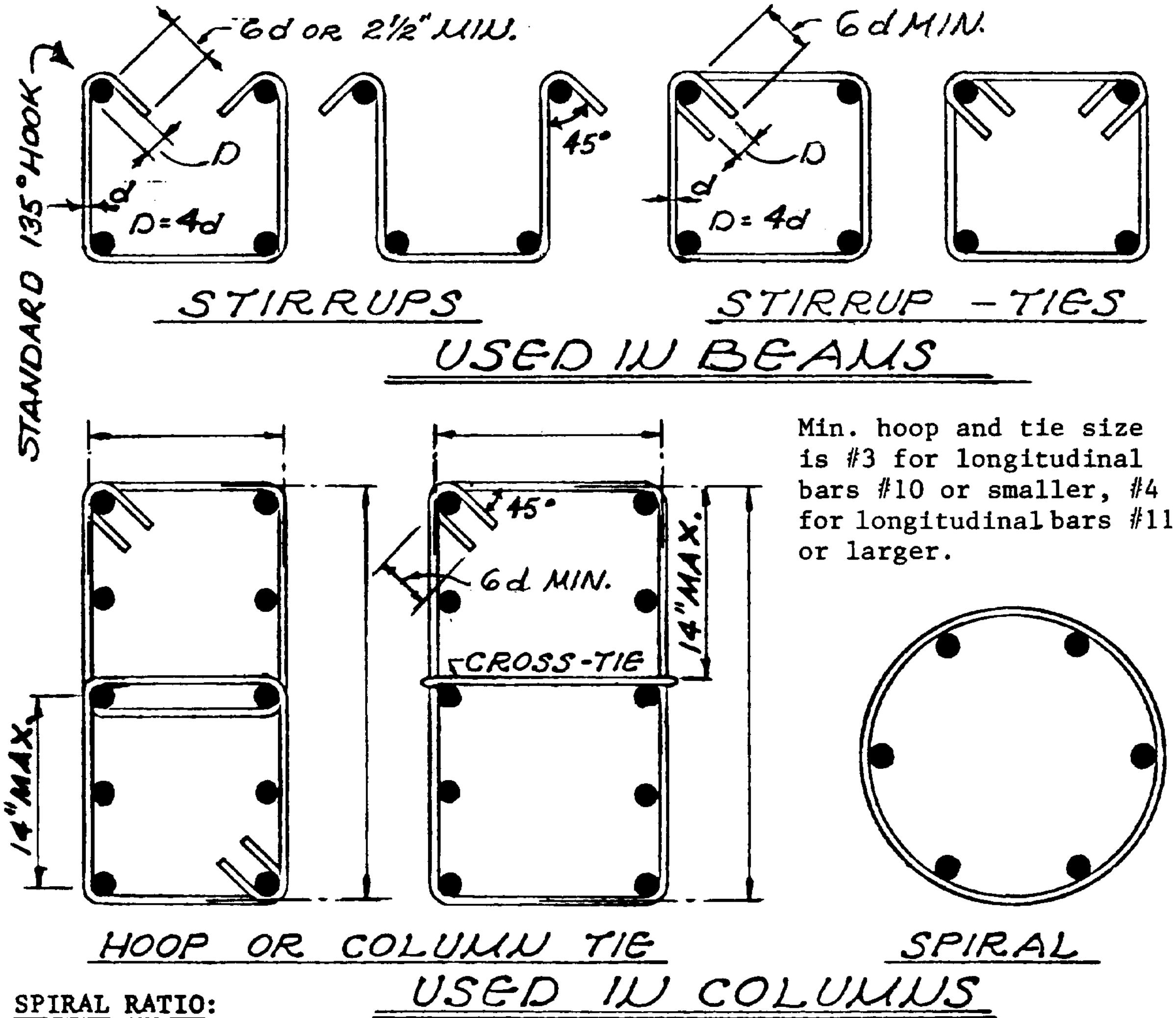


COLUMN:

l_d is the tension development length. See ACI 318-89, Sect. 12.2.

At any level, not more than alternate bars will be welded or mechanical spliced. Minimum distance between two adjacent bar splices = 24".

Figure 8-4. Type A frame—splices in reinforcement.



SPIRAL RATIO:

$$\rho_s = 0.12\,\frac{f'_c}{f_{yh}} \quad \text{or} \quad 0.45\left(\frac{A_g}{A_c}-1\right)\frac{f'_c}{f_{yh}}$$

whichever is greater.

FUNCTIONS	Stirrups	Stirrup-Ties	Column Ties	Hoops	Spirals
Shear Reinforcement And "Caging"	●	●	●	●	●
Restrain Longitudinal Steel From Buckling		●	●	●	●
Confine Concrete				●	●

HOOP REQUIREMENTS - TOTAL TIE AREA:

$$A_{sh} = 0.3\left(\frac{s h_c f'_c}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}}-1\right)$$

Formula 21-3

Formula 21-4

$$A_{sh} = 0.09\, s h_c \frac{f'_c}{f_{yh}},$$ whichever is greater.

Provide hoops or spirals in columns where special transverse reinforcement is required. (ACI 21.4.4)

Figure 8-5. Type A frame—transverse reinforcement.

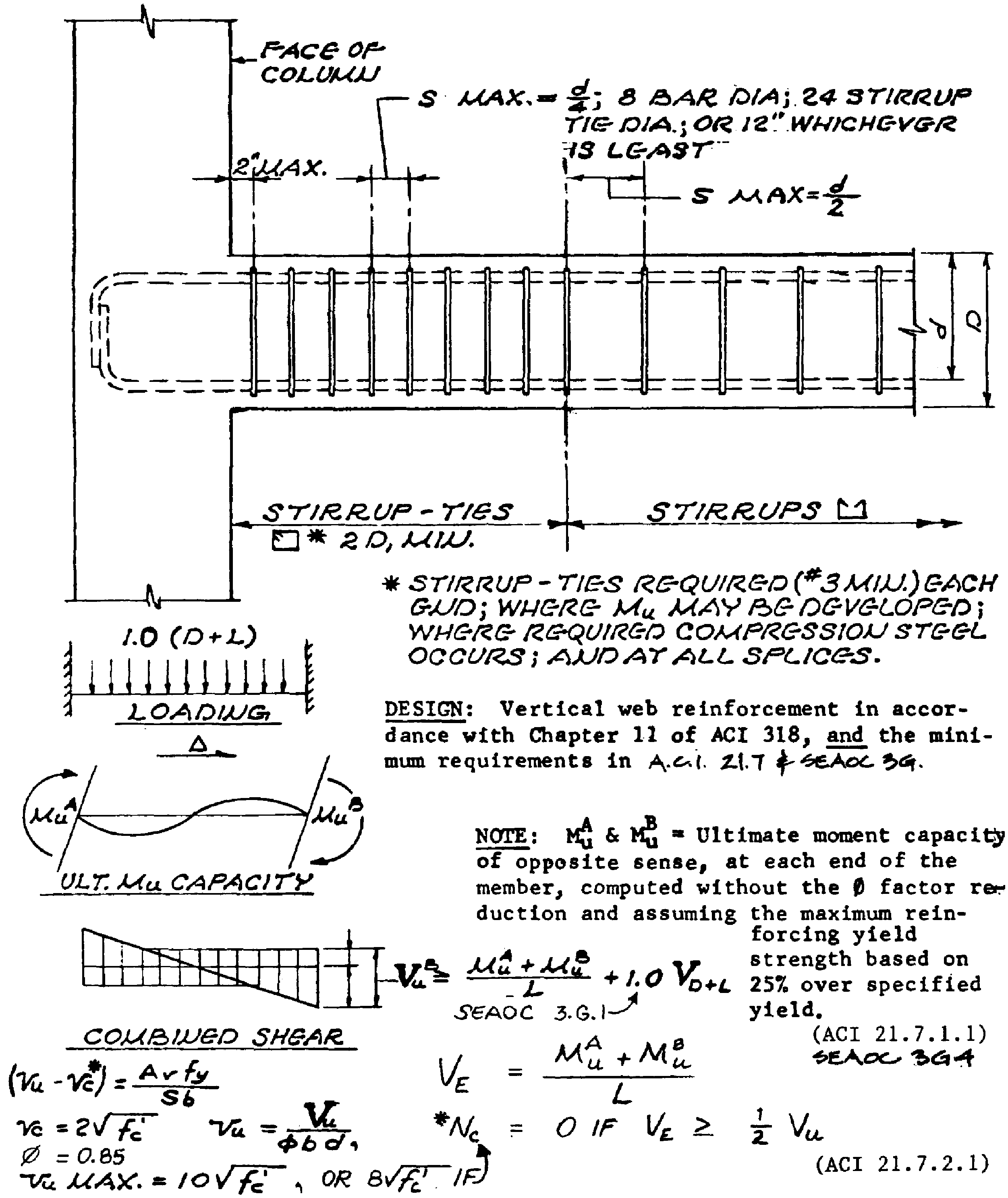


Figure 8-6. Type A frame-girder web reinforcement.

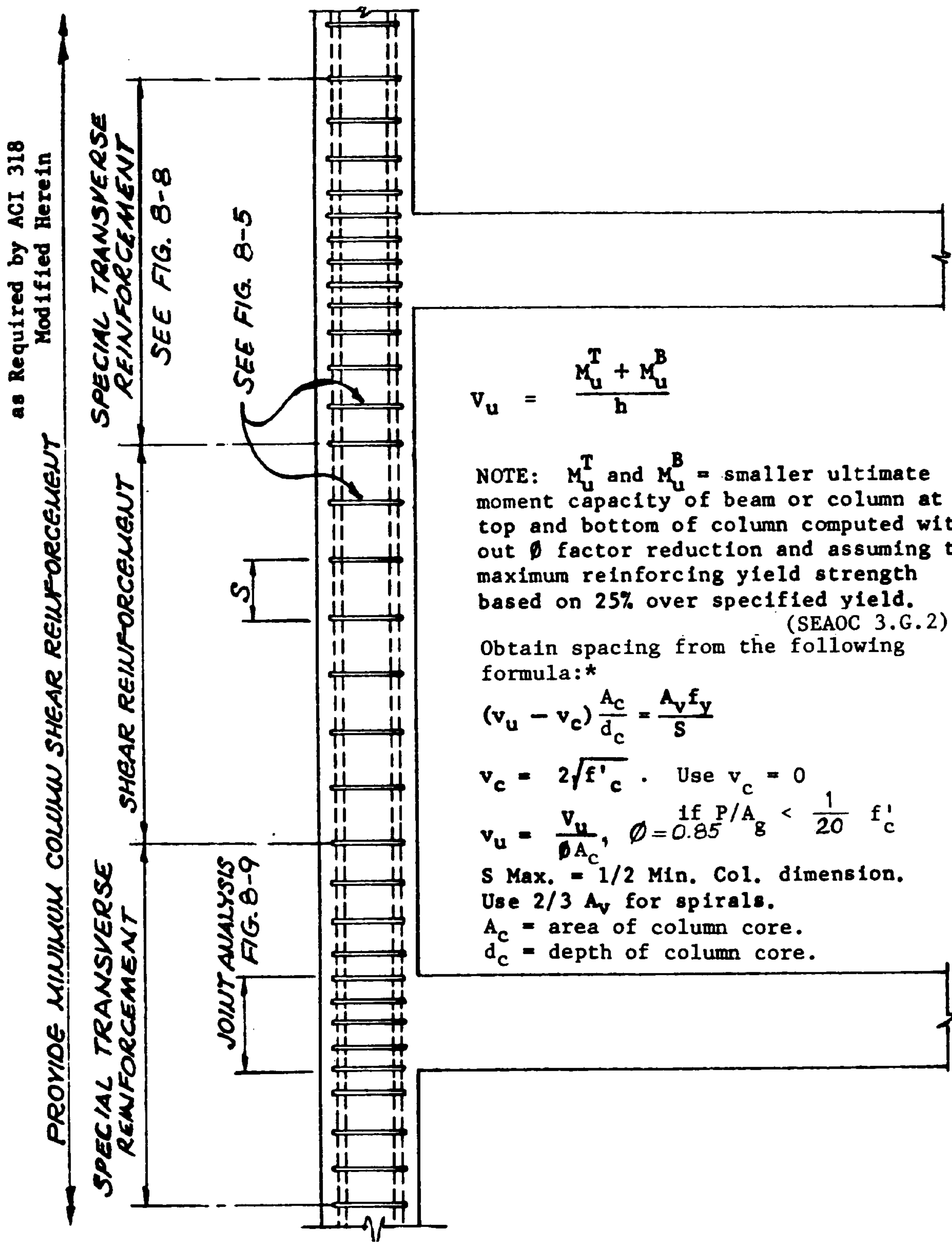
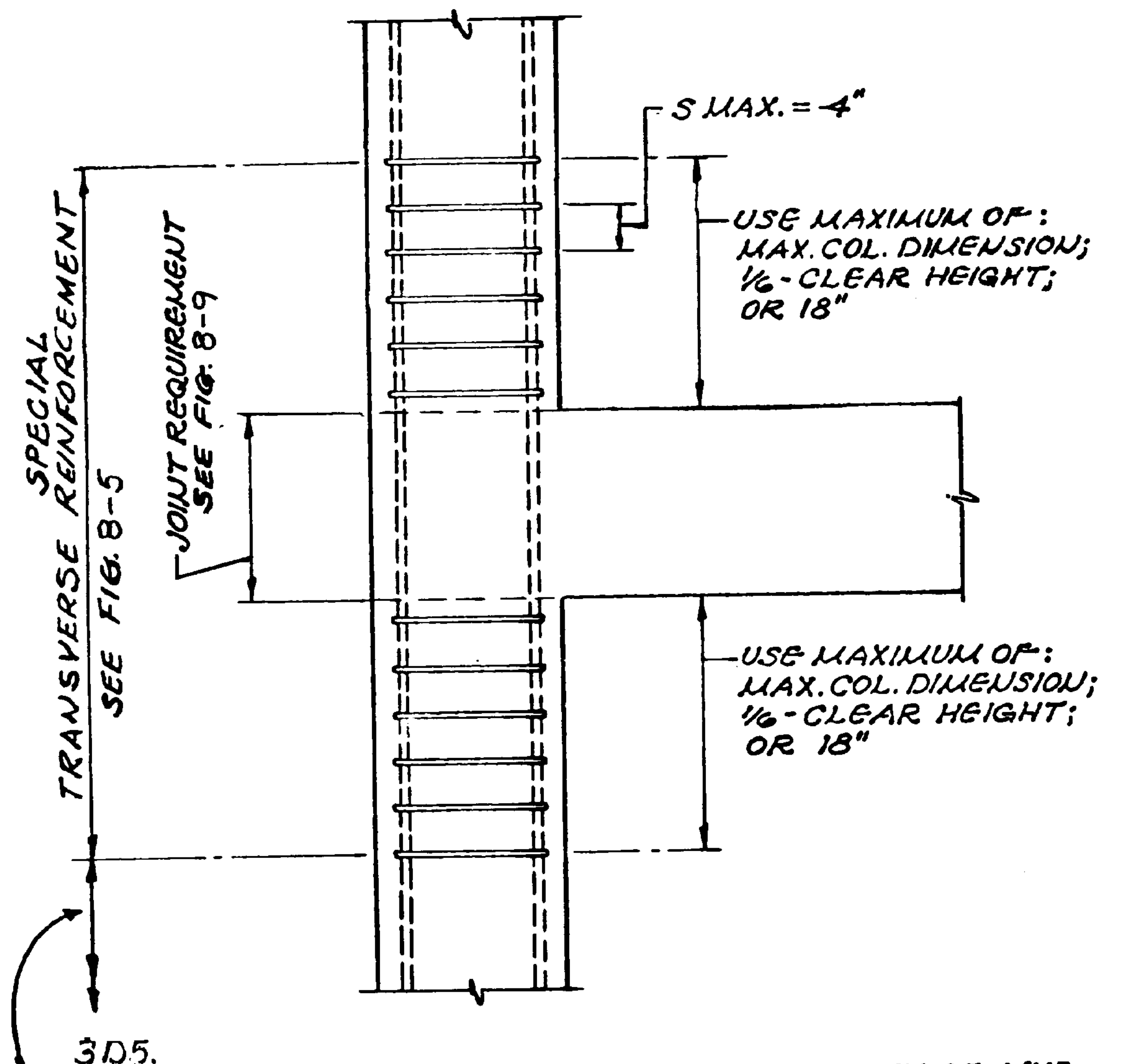


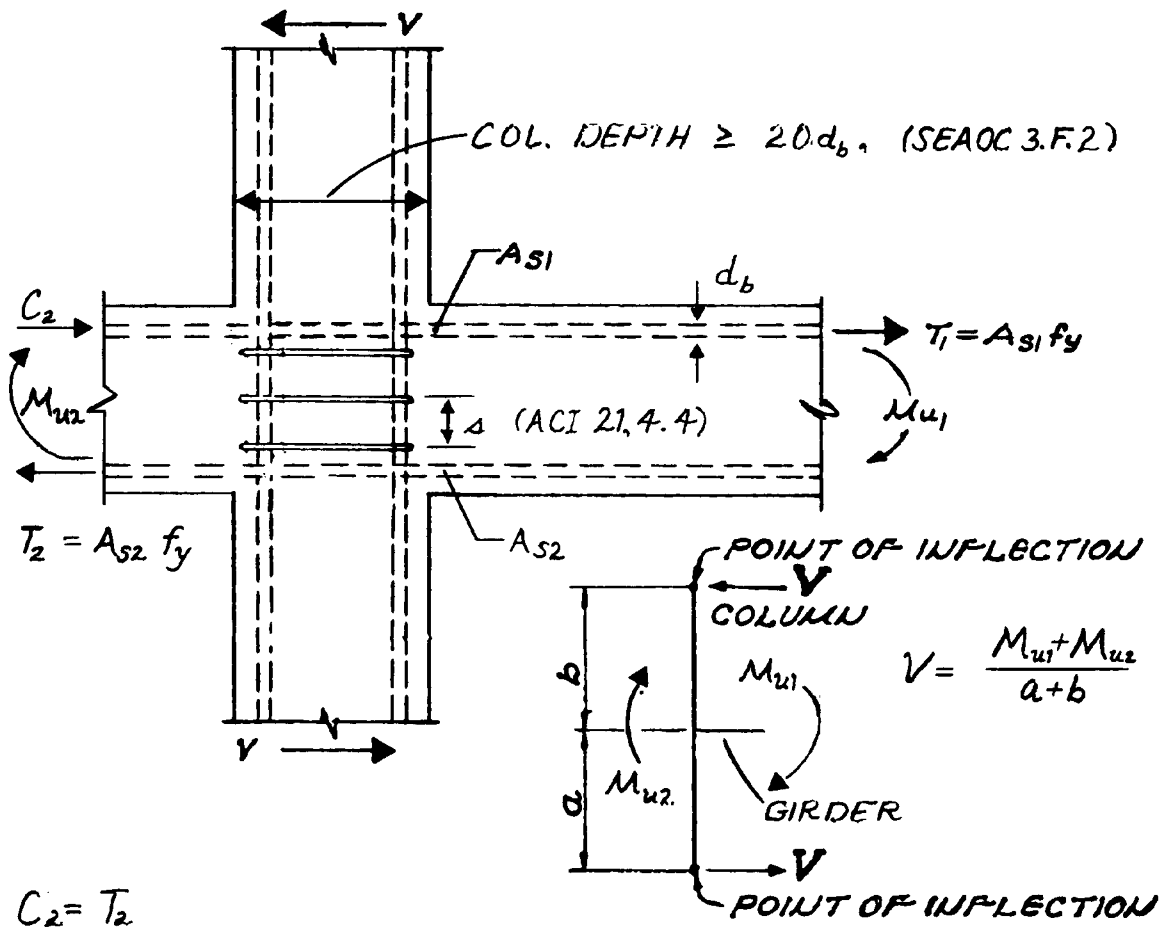
Figure 8-7. Type A frame—column transverse reinforcement.



3D5.
AT ANY SECTION WHERE THE ULTIMATE CAPACITY OF THE COLUMN (P_u) IS LESS THAN THE SUM OF THE SHEARS (ΣV_u) COMPUTED BY $V_u = \frac{M_u^A + M_u^B}{L} + 1.0V_D + L$ FOR ALL THE BEAMS ABOVE THE LEVEL UNDER CONSIDERATION, CONFINING REINFORCEMENT SHALL BE PROVIDED. SEE FIG. 8-5. THIS CONFINING REINFORCEMENT IS ALSO REQUIRED BY: SEAOC 3D6 WHEN POINT OF CONTRAFLEXURE NOT IN MIDDLE HALF OF COLUMN (ACI 21.4.4.5 AND SEAOC 3D4) FOR COLUMNS SUPPORTING DISCONTINUED STIFF MEMBERS, SUCH AS WALLS.

NOTE: A.C.I. 21.7 & SEAOC 3G SUBSTITUTE SYMBOL V_e for V_u

Figure 8-8. Type A frame—special transverse reinforcement.



$C_2 = T_2$

$V_u = T_1 + C_2 - V$

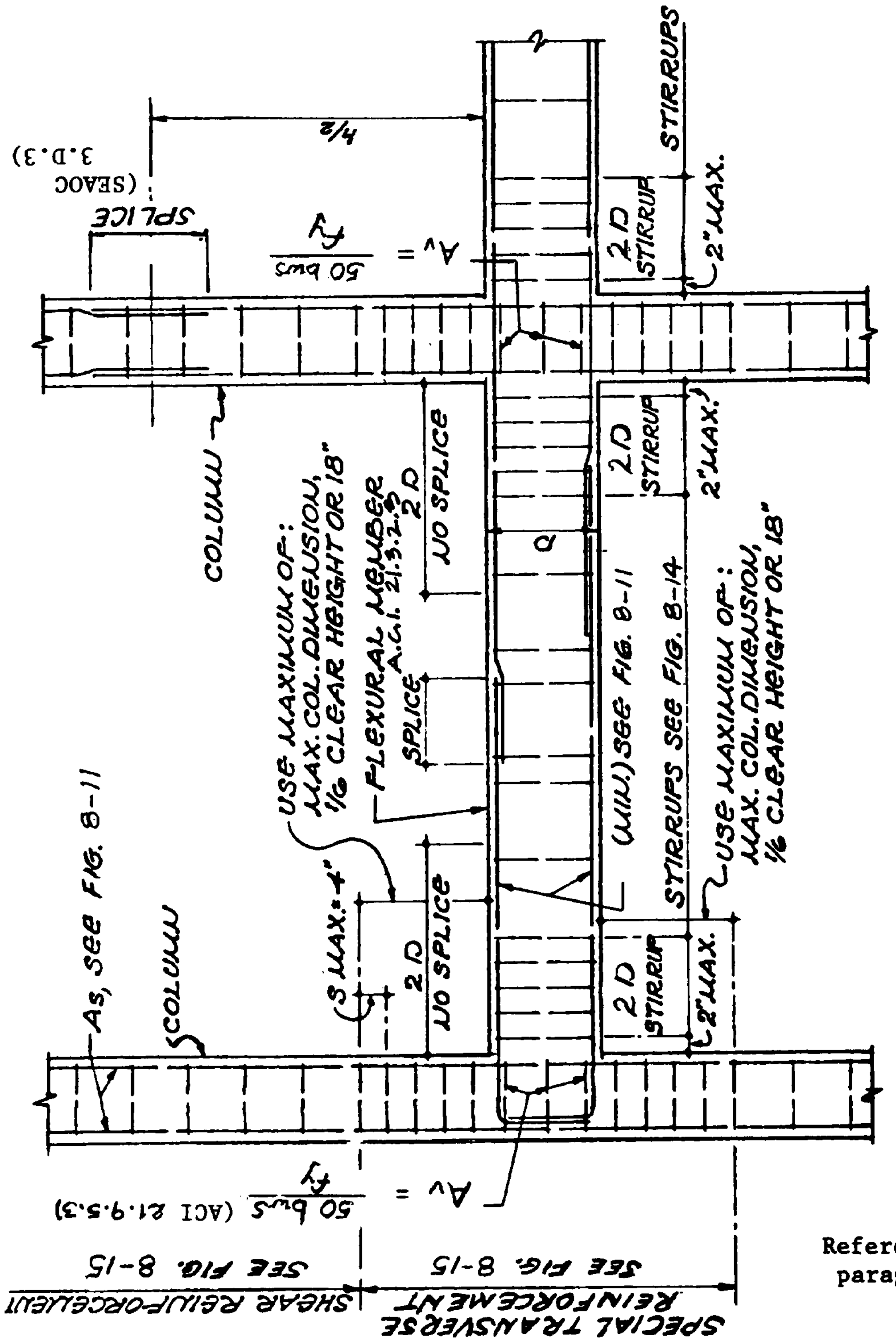
$v_u = \frac{V_u}{A_j}$, WHERE A_j IS DEFINED IN (SEAOC 3.F.1)

$S = 4''$ MAX. FOR NON-CONFINED JOINTS (ACI 21.6.2.1)

Only 1/2 the special transverse reinforcement is required for confined joints where girders frame into all four sides. (ACI 21.6.2.2)

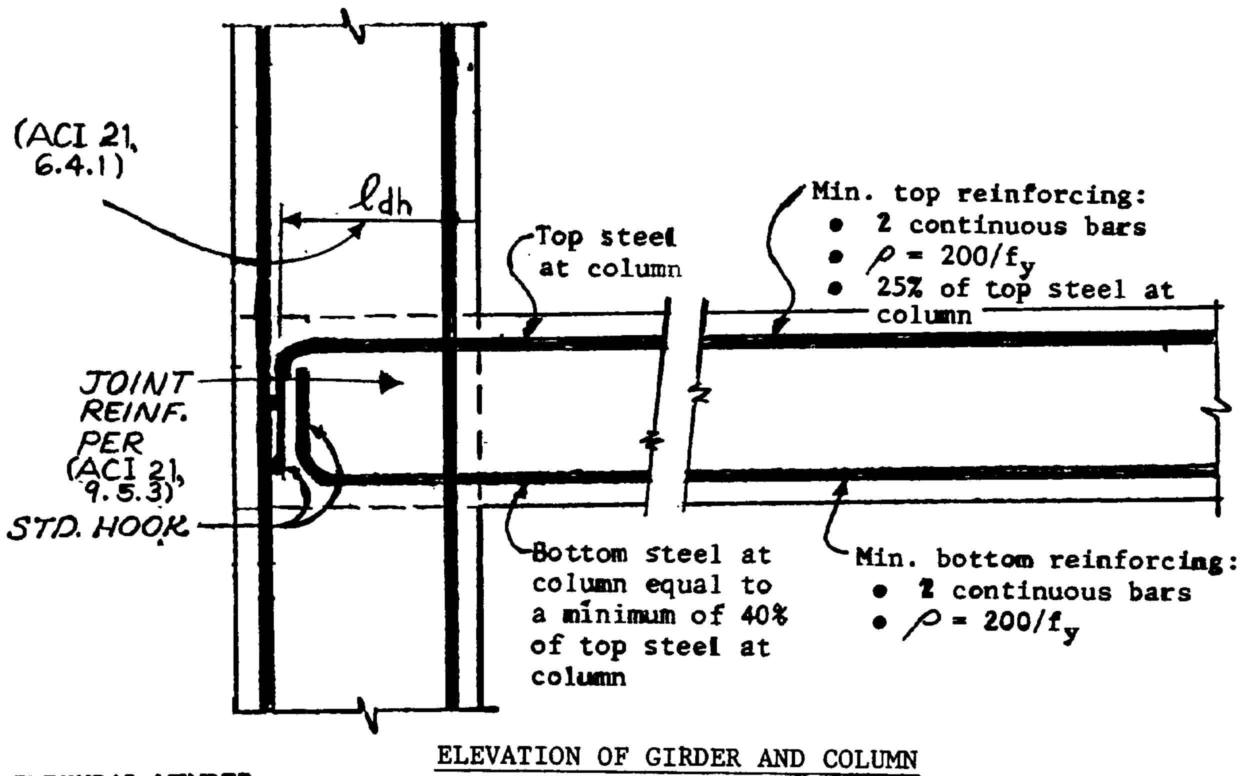
NOTE: The intersection of the orthogonal beam steel and the column steel, along with the required joint confinement hoop steel frequently results in congestion of bars. A careful study of the bar layouts should be made during design and represented on the construction documents.

Figure 8-9. Type A frame—girder-column joint analysis.



Reference:
paragraph 7-4

Figure 8-10. Type B frame—frame requirements.



FLEXURAL MEMBER:

f'_c = 3,000 p.s.i. min. at 28 days

f_y = 40 ksi or 60 ksi

Reinforcement ratio $\rho = A_s/bd$ or $\rho' = A'_s/bd$: ρ = 0.025 max.

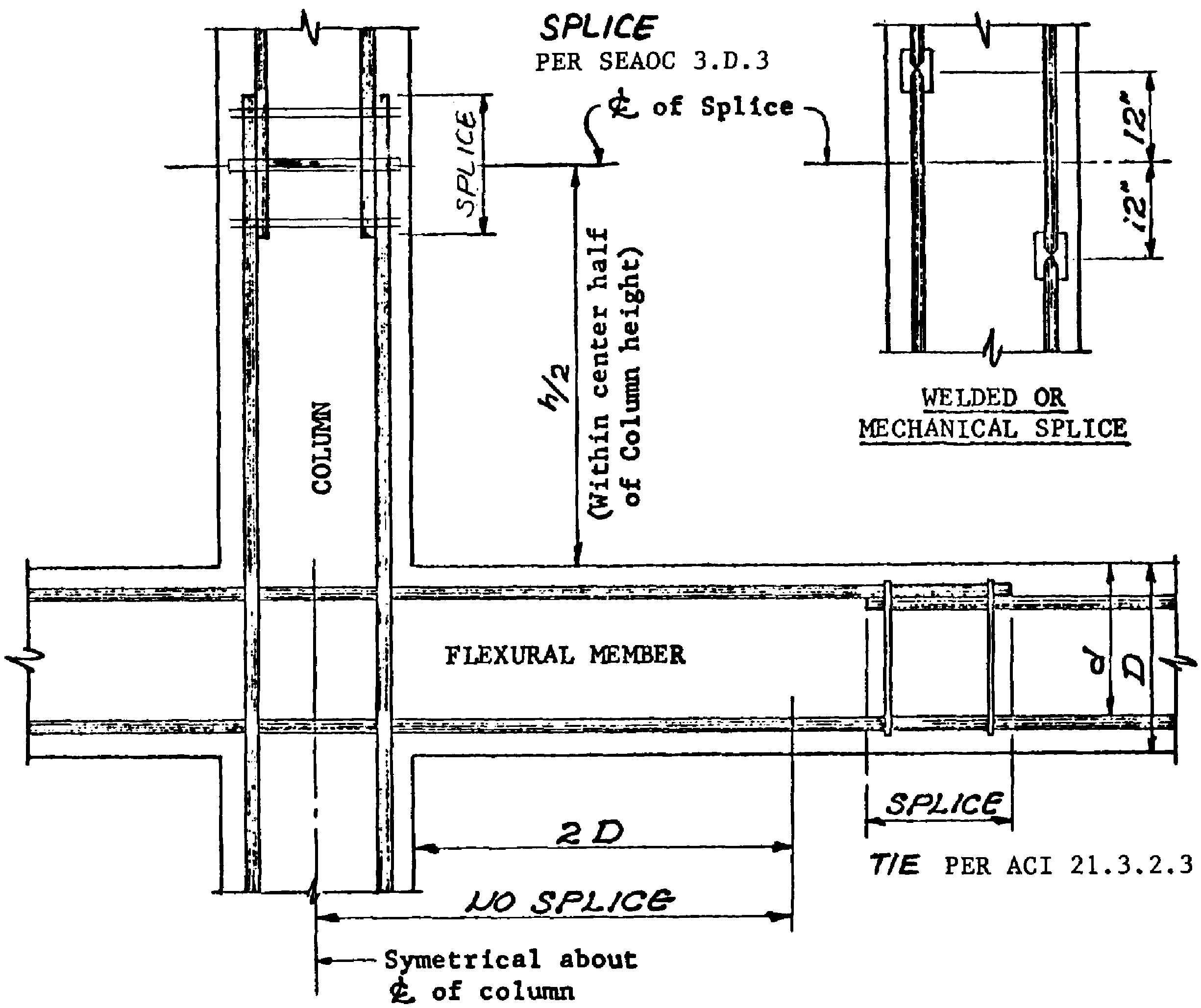
COLUMN:

f'_c = 3,000 p.s.i. at 28 days Min.

f_y = 40 ksi or 60 ksi

Reinforcement ratio, ρ (for tied columns) $\geq$ 0.01 and $\leq$ 0.06.

Figure 8-11. Type B frame-longitudinal reinforcement.

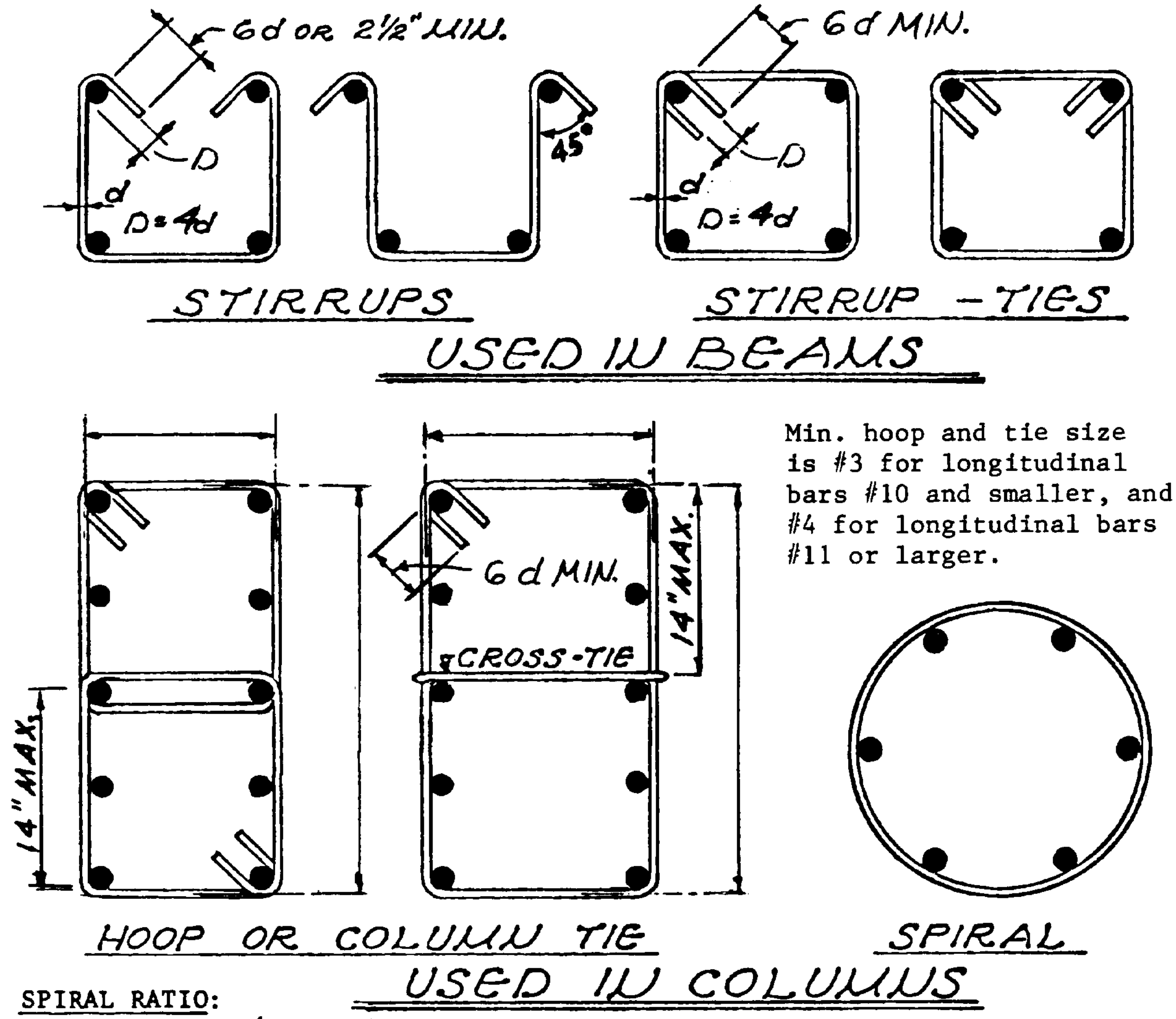


COLUMN:

l_d is the tension development length. See ACI 12.2.

At any level, not more than alternate bars will be welded or mechanical spliced. Min. distance between two adjacent bar splices = 24".

Figure 8-12. Type B frame-splices in reinforcement.



SPIRAL RATIO:

$$\rho_s = 0.08 \frac{f'_c}{f_{yh}} \quad \text{or} \quad 0.45\left(\frac{A_g}{A_c}-1\right)\frac{f'_c}{f_{yh}}$$

HOOP REQUIREMENTS - TOTAL TIE AREA:

$$A_{sh} = 0.08\ s h_c \frac{f'_c}{f_{yh}}$$

FUNCTIONS	Stirrups	Stirrup-Ties	Column Ties	Hoops	Spirals
Shear Reinforcement And "Caging"	●	●	●	●	●
Restrain Longitudinal Steel From Buckling		●	●	●	●
Confine Concrete				●	●

Figure 8-13. Type B frame—transverse reinforcement.

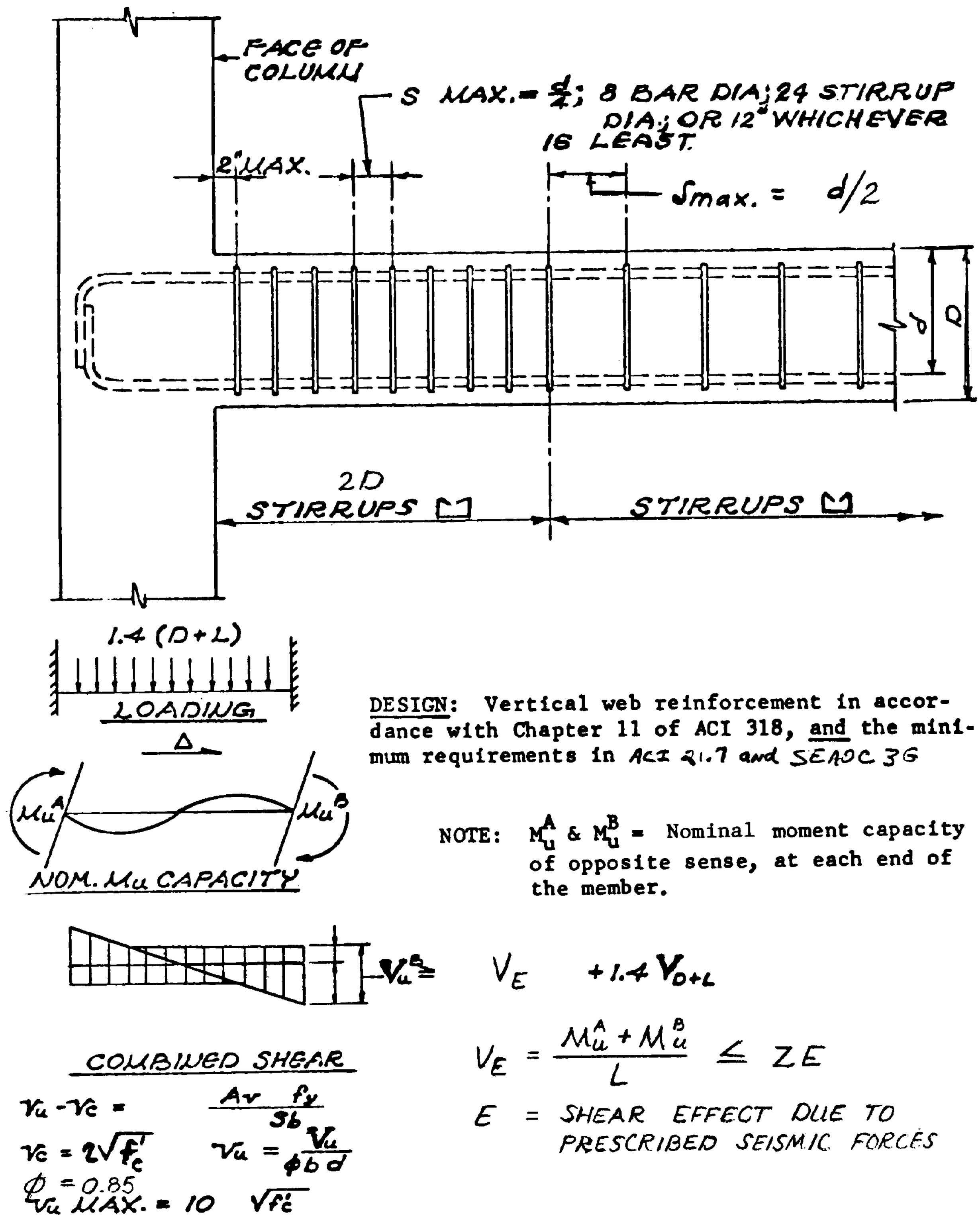


Figure 8-14. Type B frame—girder web reinforcement.

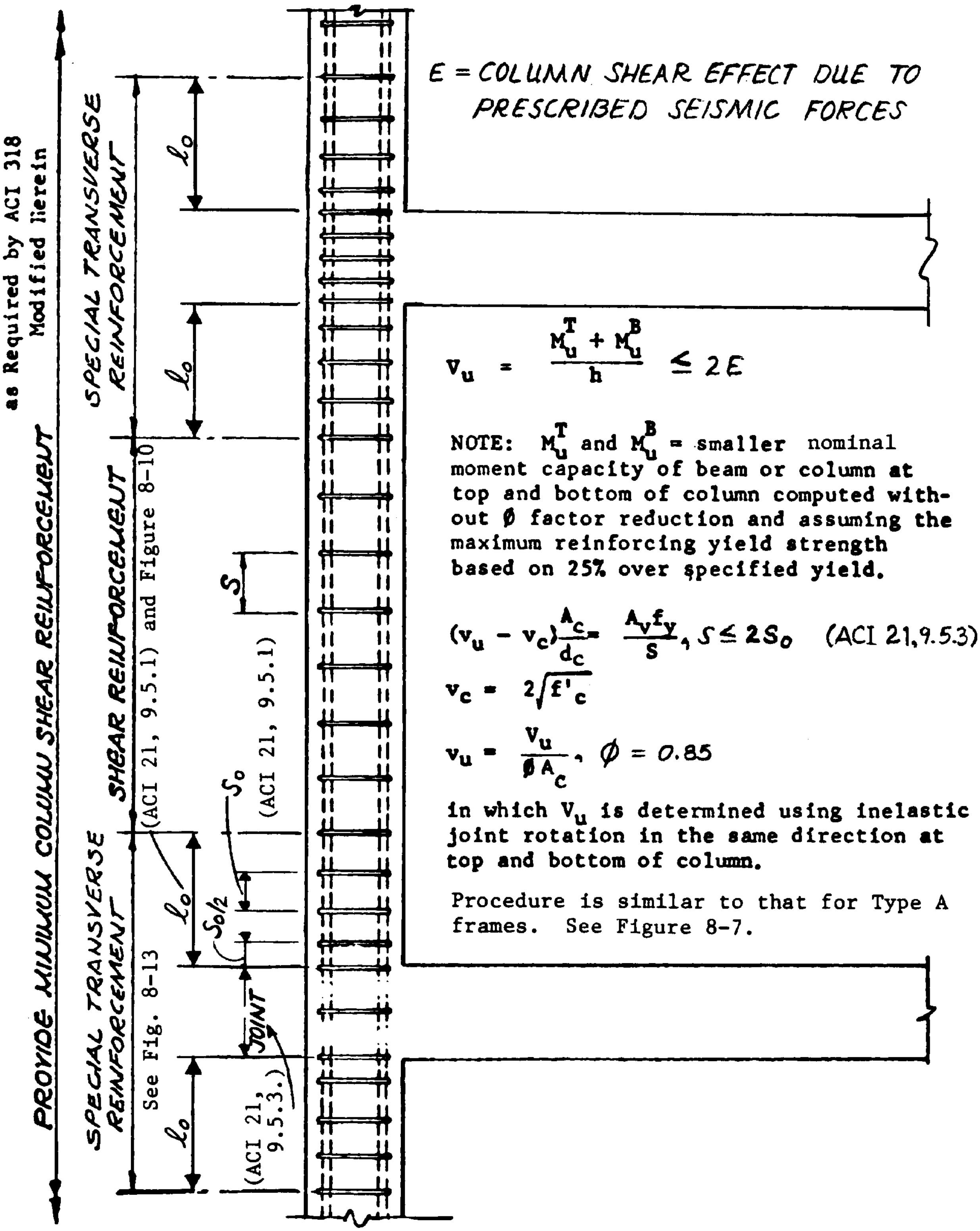


Figure 8-15. Type B frame—column transverse reinforcement.

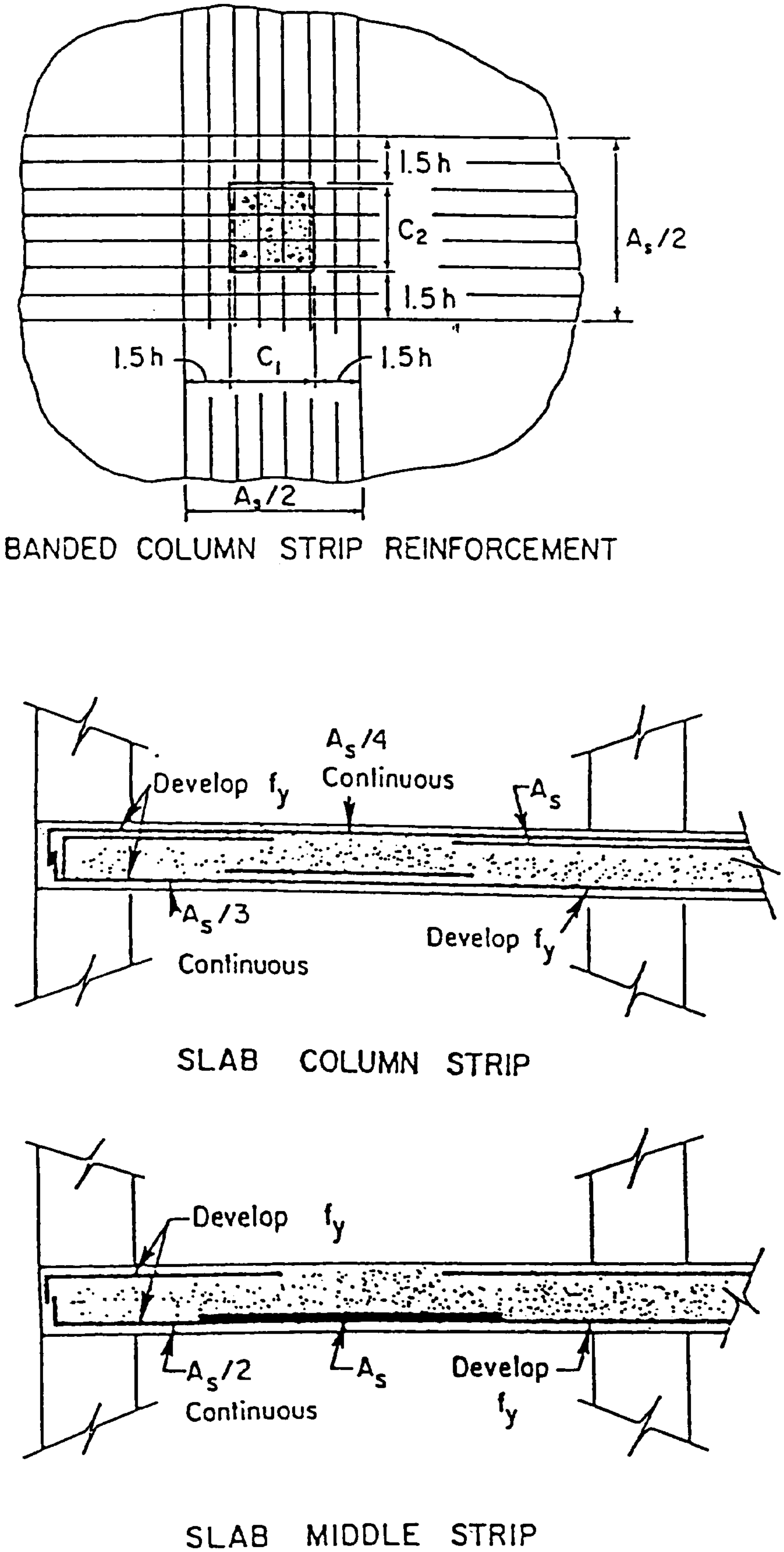


Figure 8-16. Type B frame—slab/column framing system.

$(3R_w/)E$. The punching-shear resistance shall be evaluated by using an understrength factor of ϕ = 0.6 applied to the shear resistance equations in ACI Section 11.11.

b. Development length. The development length for reinforcement in tension shall conform to ACI 21.6.4.

c. Joint reinforcement. Tie spacing within the joint shall not exceed the spacing s_o given by ACI 21.9.5.1.

d. Details. Details for Type B frames are given in figures 8-10 through 8-16.

8-6. Type C frames. This type is the SEAOC OMRF with additional seismic details intended to ensure structural integrity and collapse resistance in the event of the rare but credible earthquake in Zone 1.

a. Seismic frames. In Zone 1 the Type C frame may be used to resist lateral forces as a moment frame with R_w = 5. The design provisions are given in paragraph *c* below.

b. Nonseismic frames. In some cases, as indicated in table 8-1, frames that are intended to carry gravity loads only and are not part of the lateral force resisting system may be required to be Type C frames. The design provisions for these nonseismic frames are given in paragraph 8-8.

c. Design provisions for Type C seismic frames. In addition to the general requirements of ACI 318 Chapters 1-12, the Type C frame shall meet the following additional requirements:

(1) *Dimensional limits.* See figure 8-2.

(2) *Slab and column frames.* The same requirements as given in paragraph 8-5*a*.

(3) *Stirrups.* Web reinforcement is required throughout the length of flexural members. The reinforcement will be designed in accordance with ACI 318, except that the area of reinforcement will not be less than 0.0015 times the product of the width of the web and the spacing of the web reinforcement along the longitudinal axis of the member. The first stirrup will be located at two inches from the column face, and the next six stirrups will be placed at a spacing not greater than d/4.

(4) *Bottom bars.* Positive moment reinforcement at the supports of flexural members subject to reversal of moments will be anchored by bond, hooks, or mechanical anchors in or through the supporting member to develop the yield strength of the bars. The positive moment capacity of flexural members at columns will be at least 30 percent of the negative capacity.

(5) *Splices.* Lapped splices in flexural members, located in a region of tension or reversing stress, will be confined by at least two stirrups at each splice.

(6) *Column ties.* The spacing of ties at the ends of tied columns will not exceed 4 inches for a distance equal to the maximum column dimension but not less than one-sixth the clear height of the column from the face of the joint. The first such tie will be located 2 inches from the face of the joint.

(7) *Beam-column joints.* Joints of exterior and corner columns will be confined by lateral reinforcement through the joint. Such lateral reinforcement will consist of spirals or ties as required at the ends of columns. Tie spacing within the joint will not exceed the spacing given by Section 2 1.8.2.2 of ACI 318-89.

(8) *Development length.* The development length for reinforcement in tension shall conform to Section 21.6.4. of ACI 318-89.

8-7. Type D frames. This type is not designed for earthquake loads; however, it has some reserve strength that offers some resistance to seismic loads. The use of Type D frames is discussed below.

8-8. Nonseismic frames. A frame that is intended to carry gravity loads only, and is not considered part of the lateral force resisting system, is subject to the requirement of SEAOC 1H2d, as discussed in chapter 4. This requires the frame to be investigated and shown to be adequate for carrying vertical load when subjected to a displacement equal to $3R_w/8$ times the displacement of the lateral force resisting system of the building. The frame is considered adequate if, when the frame is so displaced, the factored moments, shears, and axial forces in the members do not exceed the nominal strengths of the members. As indicated in table 8-1, nonseismic frames are required to be Type C in Zones 2, 3, and 4 but may be Type D in Zone 1.